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Kato

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(54) **FLAT CABLE**

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Jul. 30, 2012 (JP) 2012-168114

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H01P 3/08	(2006.01)
H05K 1/02	(2006.01)

(52) **U.S. Cl.**

CPC ***H01P 3/085*** (2013.01); ***H05K 1/028*** (2013.01); ***H05K 1/0242*** (2013.01); ***H05K 1/0253*** (2013.01); *H05K 1/0221* (2013.01); *H05K 1/0225* (2013.01); *H05K 2201/055* (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC H03H 3/085; H03H 3/087

USPC 333/238, 246, 1, 4, 5, 33

See application file for complete search history.

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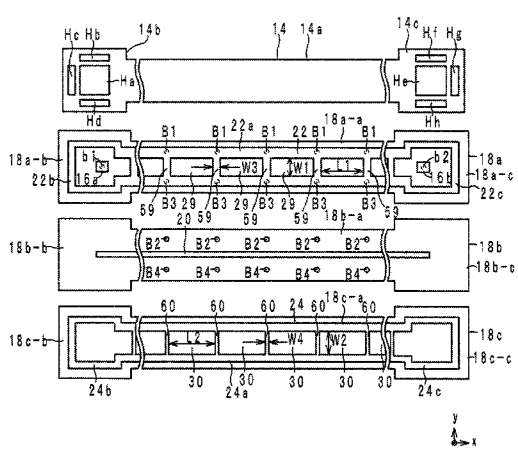
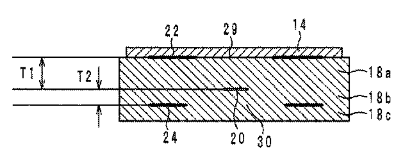
(57) **ABSTRACT**

A flat cable includes a dielectric element assembly including a plurality of dielectric layers laminated on each other, a linear signal line provided in the dielectric element assembly, a first ground conductor provided on one side in a direction of lamination relative to the signal line and including a plurality of first openings arranged along the signal line, and a second ground conductor provided on the other side in the direction of lamination relative to the signal line and including a plurality of second openings arranged along the signal line. The first ground conductor is more distant from the signal line in the direction of lamination than is the second ground conductor. The first openings are larger than the second openings.

19 Claims, 8 Drawing Sheets

12





(52) **U.S. Cl.**
CPC *H05K 2201/0969* (2013.01); *H05K 2201/09618* (2013.01); *H05K 2201/09727* (2013.01)

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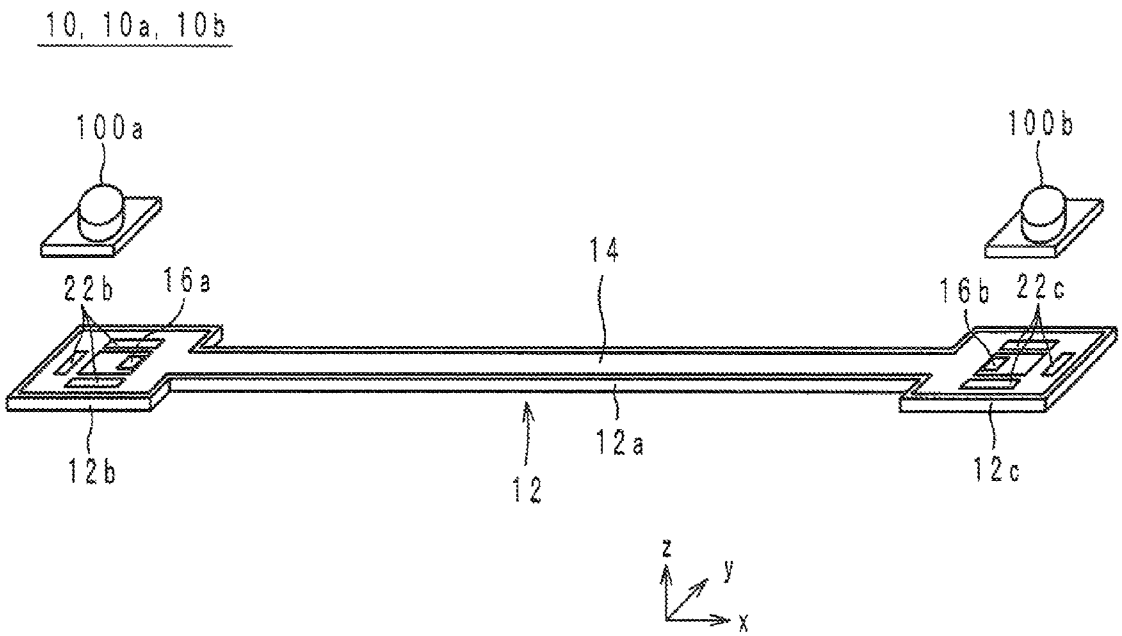
FIG. 1



F I G. 2

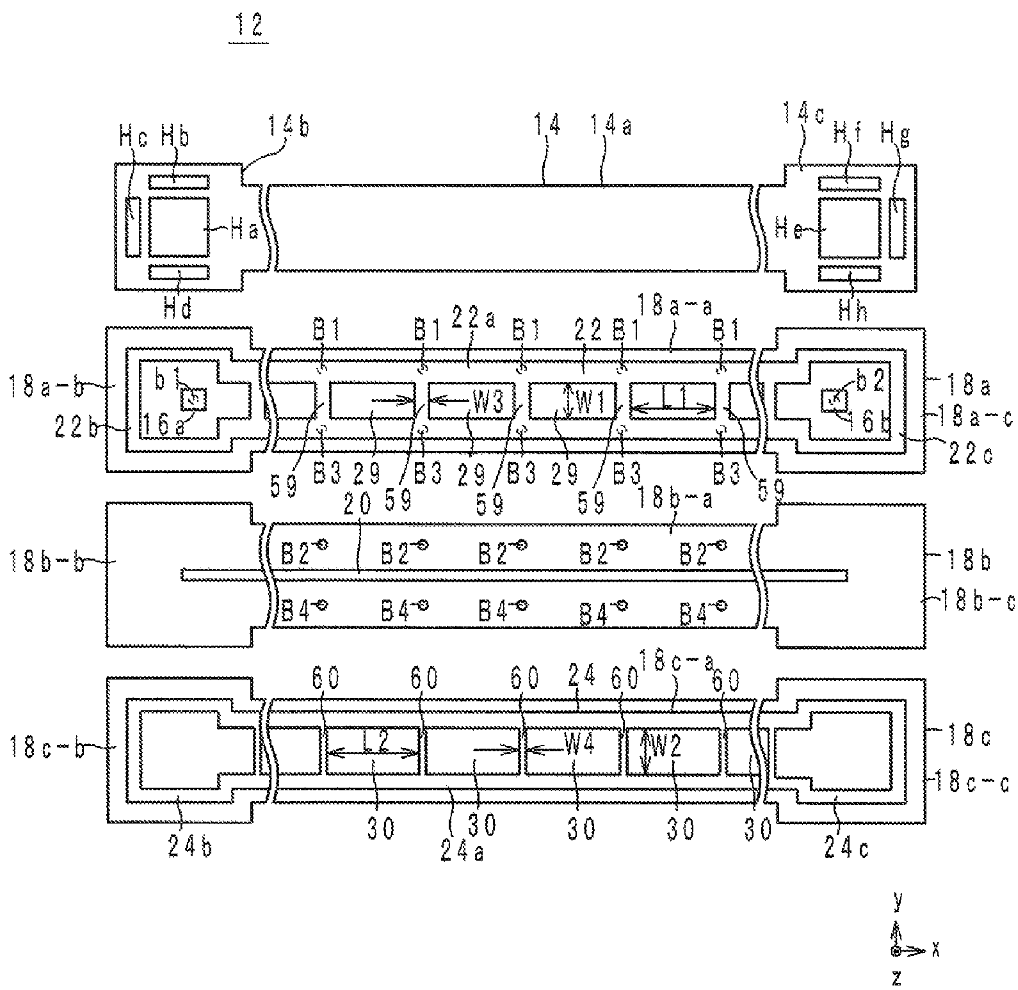

12
Hc Hb
14b
14
14a
14c
Hf
Hg
Ha
He
Hd
Hh
B1
22a
22
18a-a
18a-b
b1
b2
18a
W3
W1
L1
18a-c
22b
16a
16b
22c
59
B3
29
18b-a
20
18b-b
B2
18b
18b-c
B4
60
24
18c-a
18c-b
L2
W4
W2
18c
18c-c
24b
30
24a
24c
y
x
z

FIG. 3

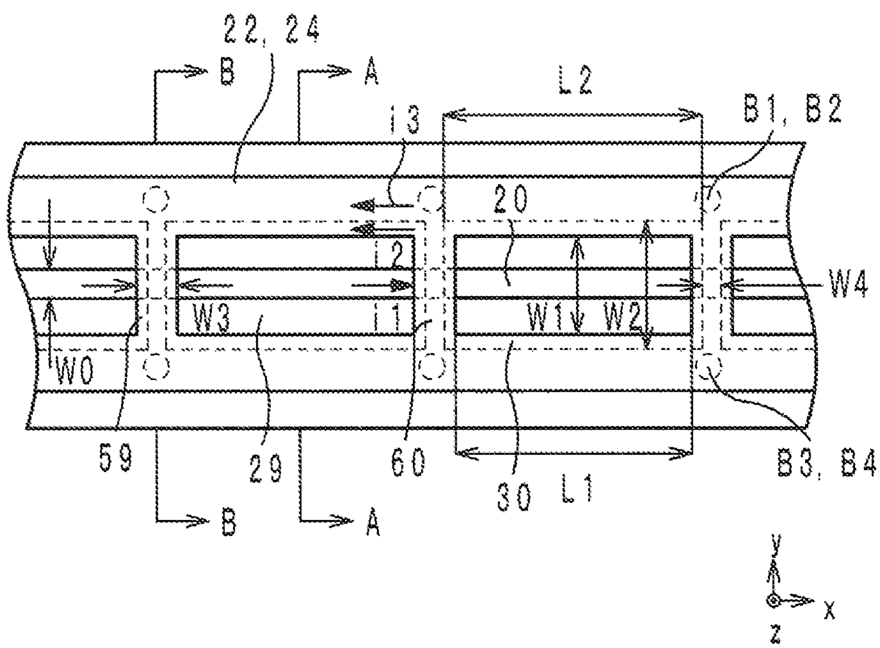


FIG. 4A

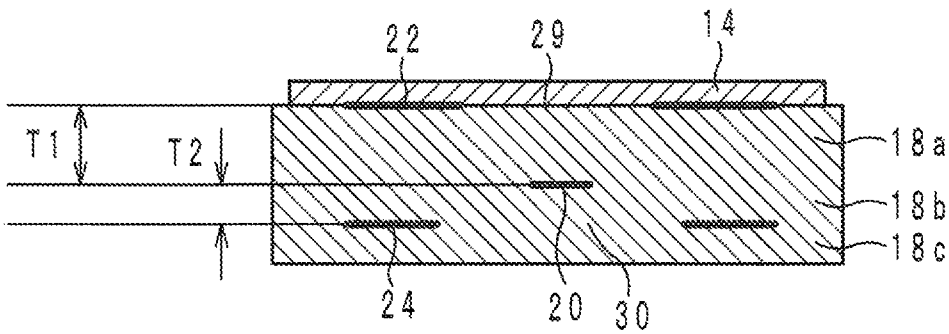
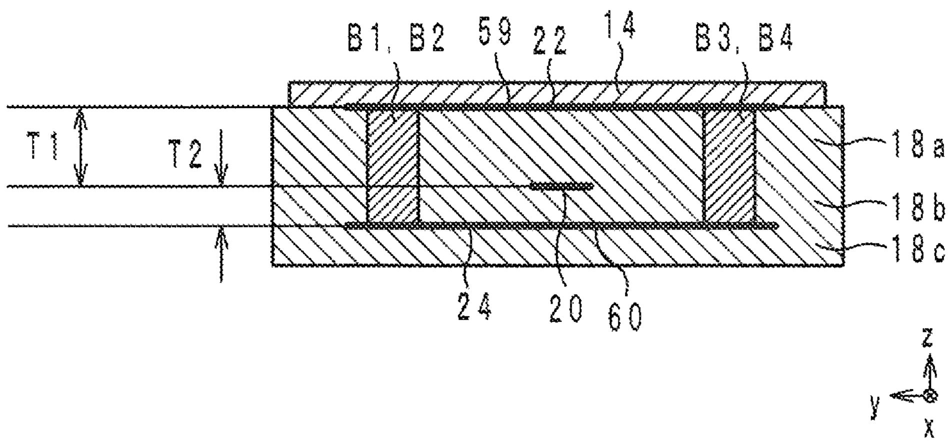
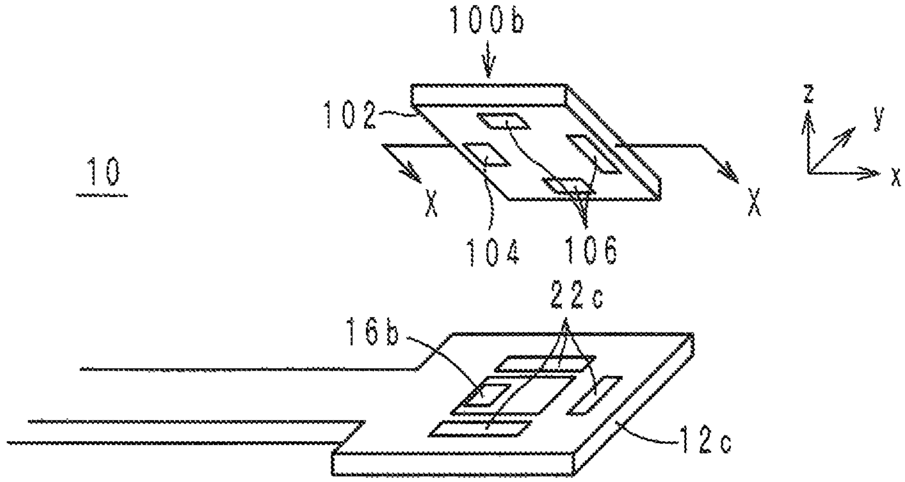

22
29
14
T1
T2
18a
18b
18c
24
20
30

FIG. 4B


B1, B2
59
22
14
B3, B4
T1
T2
18a
18b
18c
24
20
60
z
y
x

F I G . 5 A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102
10
X
X
z
y
x
104
106
22c
16b
12c

F I G . 5 B

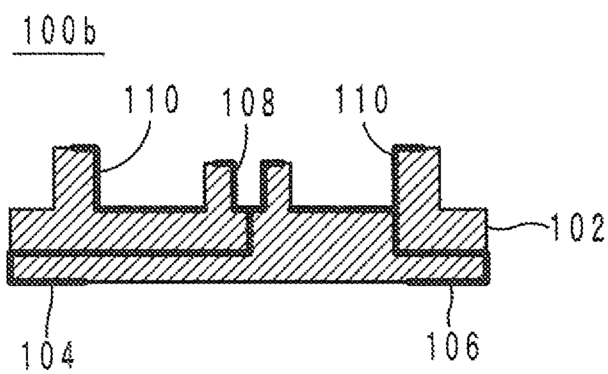

100b
110
108
110
102
104
106

FIG. 6A

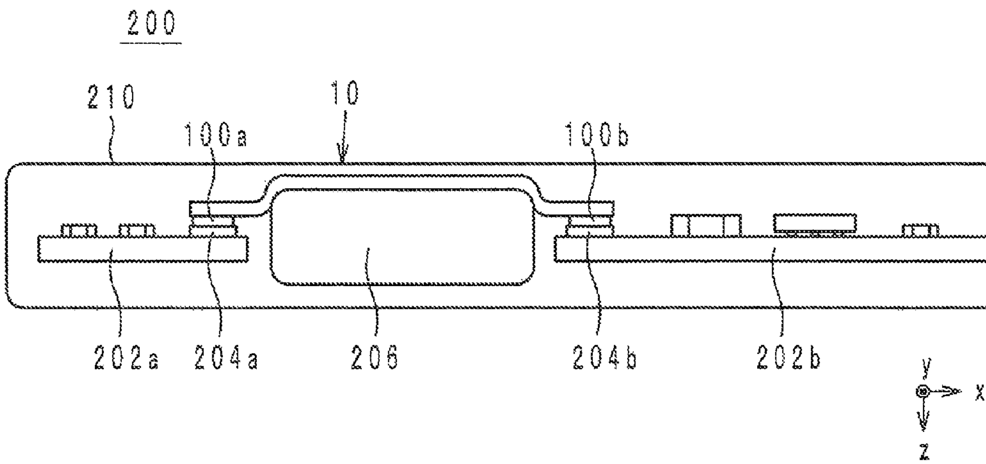
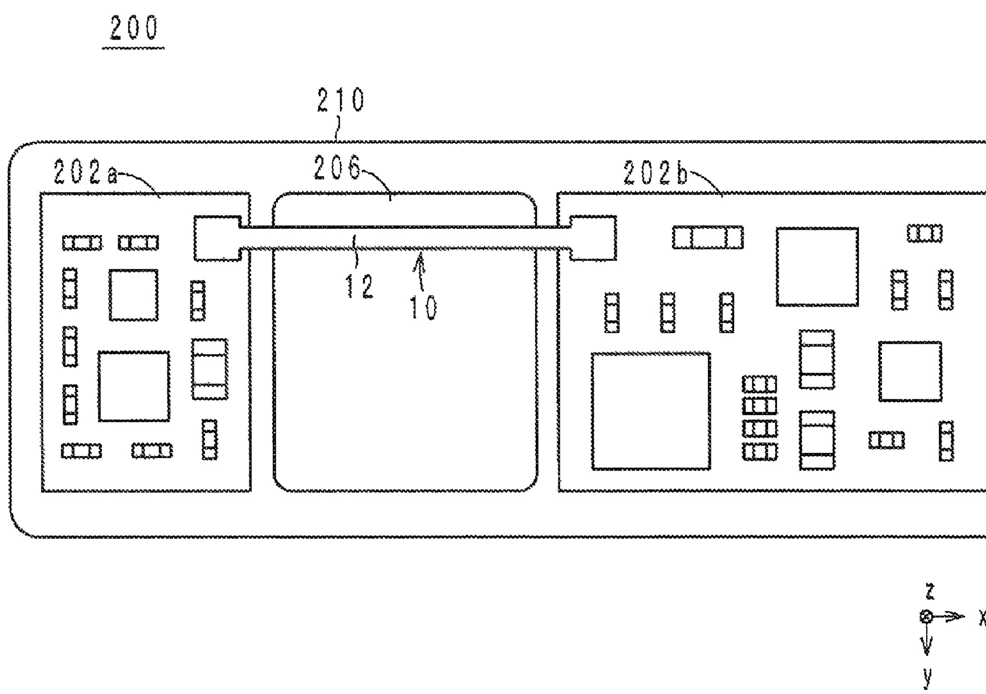

200
210
10
100a
100b
202a
204a
206
204b
202b
y
x
z

FIG. 6B


200
210
202a
206
202b
12
10
z
x
y

F I G. 7

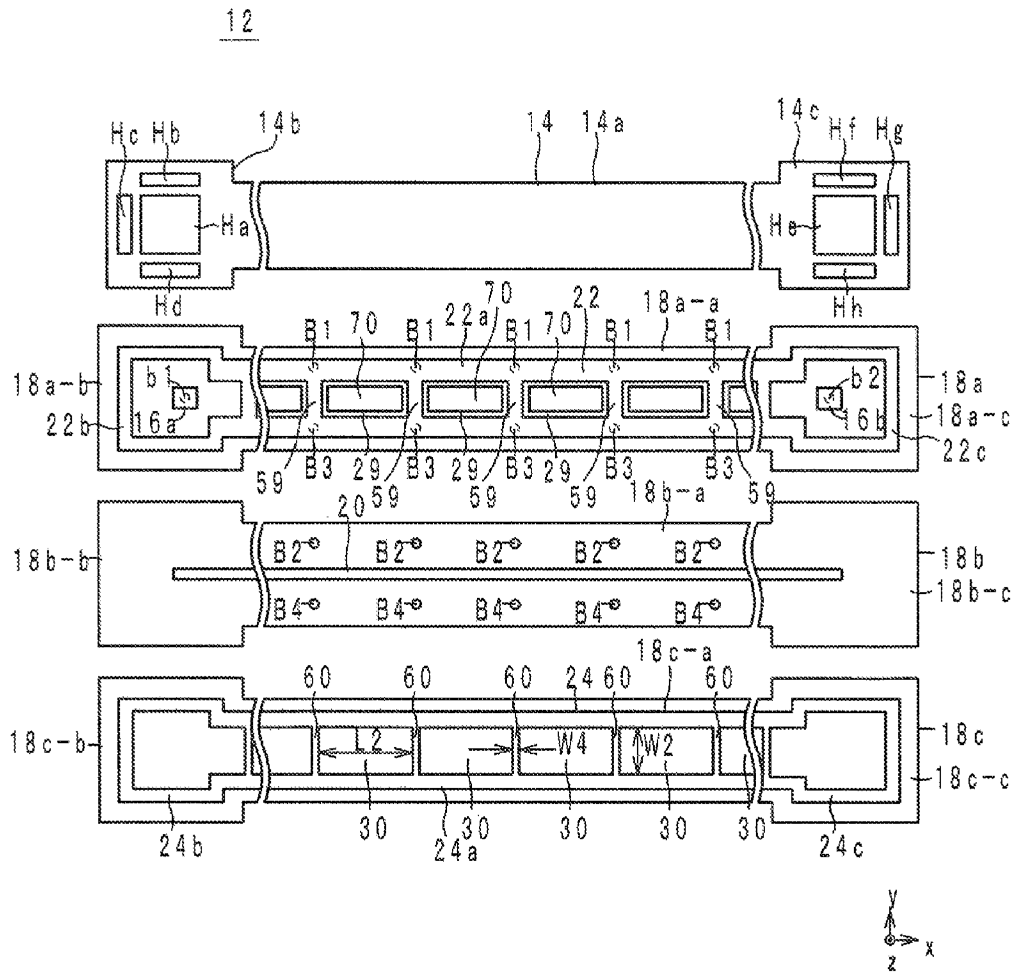

12
14b
14
14a
14c
Hc
Hb
Ha
Hd
Hf
Hg
He
Hh
B1
70
22a
22
18a-a
18a-b
22b
b1
16a
b2
16b
18a
18a-c
22c
59
B3
29
18b-a
20
B2
B4
18b-b
18b
18b-c
18c-a
60
24
18c-b
L2
W4
W2
18c
18c-c
30
24b
24a
24c
y
x
z

FIG. 8

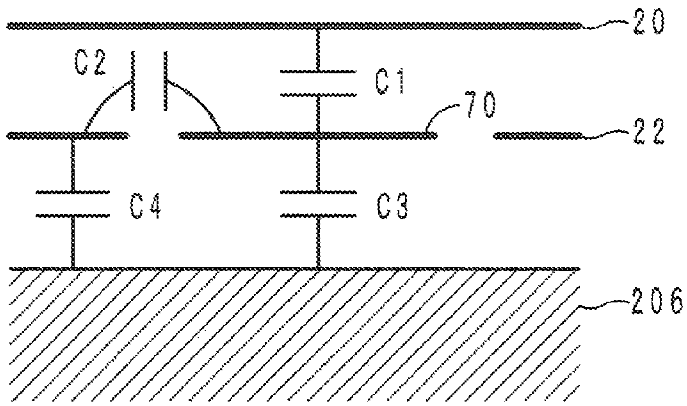
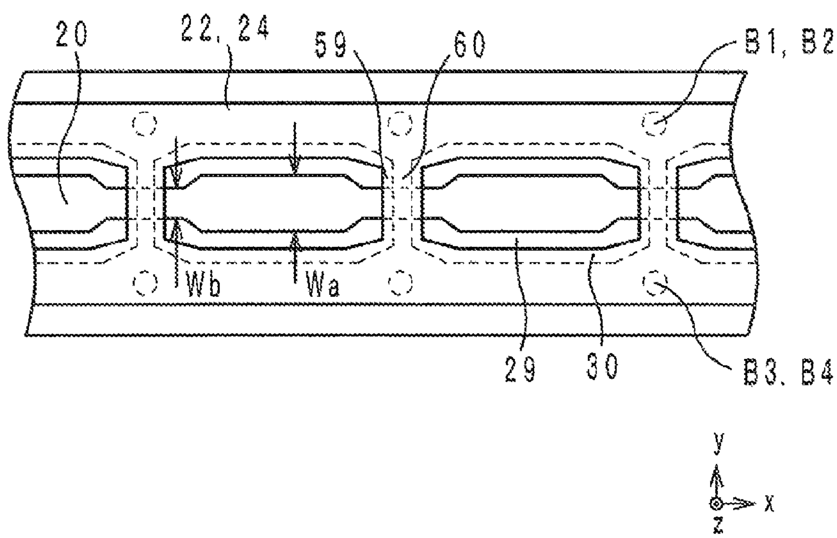


FIG. 9



FLAT CABLE

This application is based on International Application No. PCT/JP2013/066211 filed on Jun. 12, 2013, and Japanese Patent Application No. 2012-168114 filed on Jul. 30, 2012, the entire contents of each of which is hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to flat cables, more particularly to a flat cable for use in high-frequency signal transmission.

2. Description of the Related Art

As an invention related to a conventional flat cable, a high-frequency signal line described in, for example, International Publication No. WO2012/073591 (for example, see FIG. 9) is known. This high-frequency signal line includes a dielectric element assembly, a signal line, and two ground conductors. The dielectric element assembly is formed by laminating a plurality of dielectric sheets. The signal line is provided in the dielectric element assembly. The two ground conductors are provided in the dielectric element assembly such that the signal line is positioned therebetween in the direction of lamination. As a result, the signal line and the two ground conductors constitute a stripline structure.

Furthermore, each of the two ground conductors has a plurality of openings provided therein, and the openings overlap with the signal line when viewed in a plan view in the direction of lamination. This results in less capacitance being created between the signal line and the two ground conductors. Therefore, it is possible to reduce the distance between the signal line and the ground conductors in the direction of lamination, so that the high-frequency signal line can be reduced in thickness.

However, the high-frequency signal line described in International Publication No. WO2012/073591 has a problem in that the characteristic impedance of the signal line might fluctuate. More specifically, the high-frequency signal line described in International Publication No. WO2012/073591 is attached to a metallic object such as a battery pack. In this case, since the openings are provided in both of the ground conductors, the signal line faces the battery pack through the openings regardless of which side of the high-frequency signal line is directed to the battery pack. Accordingly, there is some capacitance created between the signal line and the battery pack, resulting in fluctuations in the characteristic impedance of the signal line.

Note that International Publication No. WO2011/007660 also describes a signal line having a stripline structure. This signal line also has openings provided in two ground conductors, and therefore, has a problem with fluctuations in the characteristic impedance of the signal line.

SUMMARY OF THE INVENTION

A flat cable according to a preferred embodiment of the present invention includes a dielectric element assembly including a plurality of dielectric layers laminated on each other, a linear signal line provided in the dielectric element assembly, a first ground conductor provided on one side in a direction of lamination relative to the signal line and including a plurality of first openings arranged along the signal line, and a second ground conductor provided on the other side in the direction of lamination relative to the signal line and including a plurality of second openings arranged along the

signal line. The first ground conductor is more distant from the signal line in the direction of lamination than is the second ground conductor. The first openings are larger than the second openings.

The above and other elements, features, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an external oblique view of a flat cable according to a preferred embodiment of the present invention.

FIG. **2** is an exploded view of a dielectric element assembly of the flat cable in FIG. **1**.

FIG. **3** illustrates a signal line, a reference ground conductor, and an auxiliary ground conductor of the flat cable as viewed in a plan view in the direction of lamination.

FIG. **4**A is a cross-sectional structure view of the flat cable taken along line A-A of FIG. **3**.

FIG. **4**B is a cross-sectional structure view of the flat cable taken along line B-B of FIG. **3**.

FIG. **5**A is an external oblique view of a connector of the flat cable.

FIG. **5**B is a cross-sectional structure view of the connector.

FIG. **6**A illustrates an electronic device provided with the flat cable as viewed in a plan view in the y-axis direction.

FIG. **6**B illustrates the electronic device provided with the flat cable as viewed in a plan view in the z-axis direction.

FIG. **7** is an exploded view of a dielectric element assembly of a flat cable according to a first modification of a preferred embodiment of the present invention.

FIG. **8** is an equivalent circuit diagram where the flat cable according to the first modification is attached to a battery pack.

FIG. **9** illustrates a signal line, a reference ground conductor, and an auxiliary ground conductor of a flat cable according to a second modification of a preferred embodiment of the present invention as viewed in a plan view in the direction of lamination.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, a flat cable according to preferred embodiments of the present invention will be described with reference to the drawings.

The configuration of the flat cable according to preferred embodiments of the present invention will be described below with reference to the drawings. FIG. **1** is an external oblique view of the flat cable **10** according to a preferred embodiment of the present invention. FIG. **2** is an exploded view of a dielectric element assembly **12** of the flat cable **10** in FIG. **1**. FIG. **3** illustrates a signal line **20**, a reference ground conductor **22**, and an auxiliary ground conductor **24** of the flat cable **10** as viewed in a plan view in the direction of lamination. FIG. **4**A is a cross-sectional structure view of the flat cable **10** taken along line A-A of FIG. **3**. FIG. **4**B is a cross-sectional structure view of the flat cable **10** taken along line B-B of FIG. **3**. In the following description, the direction of lamination of the flat cable **10** will be defined as a z-axis direction. In addition, the longitudinal direction of the flat cable **10** will be defined as an x-axis direction, and the direction perpendicular to the x-axis and z-axis directions will be defined as a y-axis direction.

The flat cable **10** is preferably used in, for example, an electronic device such as a cell phone in order to connect two high-frequency circuits. The flat cable **10** includes the dielectric element assembly **12**, external terminals **16***a* and **16***b*, the signal line **20**, the reference ground conductor **22**, the auxiliary ground conductor **24**, via-hole conductors b1, b2, and B1 to B4, and connectors **100***a* and **100***b*, as shown in FIGS. **1** and **2**.

The dielectric element assembly **12** is a flexible plate-shaped member, which extends in the x-axis direction when viewed in a plan view in the z-axis direction, and includes a line portion **12***a* and connecting portions **12***b* and **12***c*, as shown in FIG. **1**. The dielectric element assembly **12** includes a laminate including a protective layer **14** and dielectric sheets **18***a* to **18***c* stacked in this order, from the positive side toward the negative side in the z-axis direction, as shown in FIG. **2**. In the following, the principal surface of the dielectric element assembly **12** that is located on the positive side in the z-axis direction will be referred to as a front surface, and the principal surface of the dielectric element assembly **12** that is located on the negative side in the z-axis direction will be referred to as a back surface.

The line portion **12***a* extends in the x-axis direction, as shown in FIG. **2**. The connecting portions **12***b* and **12***c* preferably rectangular or substantially rectangular portions connected to opposite ends of the line portion **12***a* on the negative and positive sides, respectively, in the x-axis direction. The width of each of the connecting portions **12***b* and **12***c* in the y-axis direction is greater than the width of the line portion **12***a* in the y-axis direction.

The dielectric sheets **18***a* to **18***c*, when viewed in a plan view in the z-axis direction, extend in the x-axis direction and have the same shape as the dielectric element assembly **12**, as shown in FIG. **2**. The dielectric sheets **18***a* to **18***c* are preferably made of flexible thermoplastic resin such as polyimide or liquid crystal polymer.

The thickness T1 of the dielectric sheet **18***a* is greater than the thickness T2 of the dielectric sheet **18***b*, as shown in FIG. **4**. The thickness T1 preferably is, for example, about 50 μm to about 300 μm after the lamination of the dielectric sheets **18***a* to **18***c*. In the present preferred embodiment, the thickness T1 preferably is about 100 μm. Moreover, the thickness T2 preferably is, for example, about 10 μm to about 100 μm. In the present preferred embodiment, the thickness T2 preferably is about 50 μm, for example.

Furthermore, the dielectric sheet **18***a* includes a line portion **18***a-a* and connecting portions **18***a-b* and **18***a-c*. The dielectric sheet **18***b* includes a line portion **18***b-a* and connecting portions **18***b-b* and **18***b-c*. The dielectric sheet **18***c* includes a line portion **18***c-a* and connecting portions **18***c-b* and **18***c-c*. The line portions **18***a-a*, **18***b-a*, and **18***c-a* constitute the line portion **12***a*. The connecting portions **18***a-b*, **18***b-b*, and **18***c-b* constitute the connecting portion **12***b*. The connecting portions **18***a-c*, **18***b-c*, and **18***c-c* constitute the connecting portion **12***c*.

The signal line **20** is a linear conductor provided in the dielectric element assembly **12** so as to transmit a high-frequency signal, as shown in FIG. **2**. In the present preferred embodiment, the signal line **20** is provided on the front surface of the dielectric sheet **18***b*. The signal line **20** extends along the line portion **18***b-a* in the x-axis direction. The end of the signal line **20** on the negative side in the x-axis direction is positioned approximately at the center of the connecting portion **18***b-b*. The end of the signal line **20** on the positive side in the x-axis direction is positioned approximately at the center of the connecting portion **18***b-c*. The signal line **20** transmits a high-frequency signal therethrough. The width W0 of the signal line **20** (see FIG. **3**) preferably is, for example, about 300 μm to about 700 μm. In the present preferred embodiment, the width of the signal line **20** preferably is about 300 μm, for example. The signal line **20** is preferably made of a metal material mainly composed of silver or copper and having a low specific resistance. Preferably, the signal line **20** is formed by patterning metal foil formed by plating the front surface of the dielectric sheet **18***b* or by patterning metal foil attached to the front surface of the dielectric sheet **18***b*. Moreover, the surface of the signal line **20** is smoothened, so that surface roughness of the signal line **20** is greater on the side that contacts the dielectric sheet **18***b* than on the side that does not contact the dielectric sheet **18***b*.

The reference ground conductor **22** is positioned on the positive side in the z-axis direction relative to the signal line **20**. The reference ground conductor **22** includes a plurality of openings **29** arranged along the signal line **20**. More specifically, the reference ground conductor **22** is provided on the front surface of the dielectric sheet **18***a* so as to be opposite to the signal line **20** with the dielectric sheet **18***a* positioned therebetween. The reference ground conductor **22** is preferably made of a metal material mainly composed of silver or copper and having a low specific resistance. Here, the reference ground conductor **22** is preferably formed by patterning metal foil formed by plating the front surface of the dielectric sheet **18***a* or by patterning metal foil attached to the front surface of the dielectric sheet **18***a*. Moreover, the surface of the reference ground conductor **22** is smoothened, so that surface roughness of the reference ground conductor **22** is greater on the side that contacts the dielectric sheet **18***a* than on the side that does not contact the dielectric sheet **18***a*.

Furthermore, the reference ground conductor **22** includes a line portion **22***a* and terminal portions **22***b* and **22***c*. The line portion **22***a* is provided on the front surface of the line portion **18***a-a* so as to extend in the x-axis direction. The terminal portion **22***b* is provided in the form of a rectangular loop on the front surface of the connecting portion **18***a-b*. The terminal portion **22***b* is connected to the end of the line portion **22***a* on the negative side in the x-axis direction. The terminal portion **22***c* is provided in the form of a rectangular or substantially loop on the front surface of the connecting portion **18***a-c*. The terminal portion **22***c* is connected to the end of the line portion **22***a* on the positive side in the x-axis direction.

Furthermore, the line portion **22***a* includes a plurality of rectangular or substantially rectangular openings **29** provided so as to extend in the x-axis direction, as shown in FIG. **2**. Accordingly, the reference ground conductor **22** is in the form of a ladder in the line portion **22***a*. Moreover, the portions of the reference ground conductor **22** that are positioned between adjacent openings **29** will be referred to as bridge portions **59**. The openings **29** and the bridge portions **59**, when viewed in a plan view in the z-axis direction, alternatingly overlap with the signal line **20**. In the present preferred embodiment, the signal line **20** crosses the openings **29** and the bridge portions **59** in the x-axis direction, approximately at their centers in the y-axis direction.

The auxiliary ground conductor **24** is positioned on the negative side in the z-axis direction relative to the signal line **20**. The auxiliary ground conductor **24** has a plurality of openings **30** arranged along the signal line **20**. More specifically, the auxiliary ground conductor **24** is provided on the front surface of the dielectric sheet **18***c* so as to be opposite to the signal line **20** with the dielectric sheet **18***b* positioned therebetween. The auxiliary ground conductor **24** is made of a metal material mainly composed of silver or copper and having a low specific resistance. Here, the auxiliary ground conductor **24** is preferably formed by patterning metal foil formed by plating the front surface of the dielectric sheet **18***c* or by patterning metal foil attached to the front surface of the dielectric sheet **18***c*. Moreover, the surface of the auxiliary ground conductor **24** is smoothened, so that surface roughness of the auxiliary ground conductor **24** is greater on the side that contacts the dielectric sheet **18***c* than on the side that does not contact the dielectric sheet **18***c*.

Furthermore, the auxiliary ground conductor **24** includes a line portion **24***a* and terminal portions **24***b* and **24***c*. The line portion **24***a* is provided on the front surface of the line portion **18***c-a* so as to extend in the x-axis direction. The terminal portion **24***b* is provided in the form of a rectangular or substantially rectangular loop on the front surface of the connecting portion **18***c-b*. The terminal portion **24***b* is connected to the end of the line portion **24***a* on the negative side in the x-axis direction. The terminal portion **24***c* is provided in the form of a rectangular or substantially rectangular loop on the front surface of the connecting portion **18***c-c*. The terminal portion **24***c* is connected to the end of the line portion **24***a* on the positive side in the x-axis direction.

Furthermore, the line portion **24***a* includes a plurality of rectangular or substantially rectangular openings **30** provided so as to extend in the x-axis direction, as shown in FIG. **2**. Accordingly, the auxiliary ground conductor **24** is in the form of a ladder in the line portion **24***a*. Moreover, the portions of the auxiliary ground conductor **24** that are positioned between adjacent openings **30** will be referred to as bridge portions **60**. The bridge portions **60** extend in the y-axis direction. The openings **30** and the bridge portions **60**, when viewed in a plan view in the z-axis direction, alternatingly overlap with the signal line **20**. In the present preferred embodiment, the signal line **20** crosses the openings **30** and the bridge portions **60** in the x-axis direction, approximately at their centers in the y-axis direction.

The openings **29** and **30** and the bridge portions **59** and **60** will now be described in terms of their sizes and positional relationship with reference to FIG. **3**. The openings **29** and **30** overlap with each other, as shown in FIG. **3**. The openings **29** are smaller than the openings **30**. More specifically, the width W1 of the openings **29** in the y-axis direction, which is perpendicular to the direction (x-axis direction) in which the signal line **20** extends, is less than the width W2 of the openings **30** in the y-axis direction. The width W1 of the openings **29** preferably is, for example, from about 500 μm to about 900 μm. The width W2 of the openings **30** preferably is, for example, from about 1000 μm to about 2000 μm. In addition, the length L1 of the openings **29** in the x-axis direction is shorter than the length L2 of the openings **30** in the x-axis direction. The length L1 of the openings **29** preferably is, for example, from about 2 mm to about 7 mm. The length L2 of the openings **30** preferably is, for example, from about 2 mm to about 7 mm. The openings **29**, when viewed in a plan view in the z-axis direction, are positioned within the openings **30**. Accordingly, when viewed in a plan view in the z-axis direction, the edges of the openings **29** do not overlap with the edges of the openings **30**.

Furthermore, the bridge portions **60** overlap with the bridge portions **59**, as shown in FIG. **3**. The width W3 of the bridge portions **59** are greater than the width W4 of the bridge portions **60**. The width W3 of the bridge portions **59** preferably is, for example, from about 50 μm to about 200 μm. The width W4 of the bridge portions **60** preferably is, for example, from about 50 μm to about 200 μm. Accordingly, when viewed in a plan view in the z-axis direction, the bridge portions **60** overlap with the bridge portions **59** without extending beyond the edges of bridge portions **59**.

The external terminal **16***a* is a rectangular or substantially rectangular conductor provided at the center of the front surface of the connecting portion **18***a-b*, as shown in FIGS. **1** and **2**. Accordingly, the external terminal **16***a*, when viewed in a plan view in the z-axis direction, overlaps with the end of the signal line **20** on the negative side in the x-axis direction. The external terminal **16***b* is a rectangular or substantially rectangular conductor provided at the center of the front surface of the connecting portion **18***a-c*, as shown in FIGS. **1** and **2**. Accordingly, the external terminal **16***b*, when viewed in a plan view in the z-axis direction, overlaps with the end of the signal line **20** on the positive side in the x-axis direction. The external terminals **16***a* and **16***b* are preferably made of a metal material mainly composed of silver or copper and having a low specific resistance. Moreover, the surfaces of the external terminals **16***a* and **16***b* are plated with Ni and Au. Here, the external terminals **16***a* and **16***b* are preferably formed by patterning metal foil formed by plating the front surface of the dielectric sheet **18***a* or by patterning metal foil attached to the front surface of the dielectric sheet **18***a*. Moreover, the surfaces of the external terminals **16***a* and **16***b* are smoothened, so that surface roughness of the external terminals **16***a* and **16***b* is greater on the side that contacts the dielectric sheet **18***a* than on the side that does not contact the dielectric sheet **18***a*.

As described above, the signal line **20** is positioned between the reference ground conductor **22** and the auxiliary ground conductor **24** in the z-axis direction. That is, the signal line **20**, the reference ground conductor **22**, and the auxiliary ground conductor **24** constitute a triplate stripline structure. Moreover, the gap between the signal line **20** and the reference ground conductor **22** (their distance in the z-axis direction) is equal or approximately equal to the thickness T1 of the dielectric sheet **18***a*, as shown in FIG. **4**, and it preferably is, for example, about 50 μm to about 300 μm. In the present preferred embodiment, the gap between the signal line **20** and the reference ground conductor **22** preferably is about 100 μm. On the other hand, the gap between the signal line **20** and the auxiliary ground conductor (their distance in the z-axis direction) is equal or approximately equal to the thickness T2 of the dielectric sheet **18***b*, as shown in FIG. **4**, and it preferably is, for example, about 10 μm to about 100 μm. In the present preferred embodiment, the gap between the signal line **20** and the auxiliary ground conductor **24** preferably is about 50 μm. That is, the distance between the reference ground conductor **22** and the signal line **20** in the z-axis direction is designed to be greater than the distance between the auxiliary ground conductor **24** and the signal line **20** in the z-axis direction.

The via-hole conductor b1 pierces through the connecting portion **18***a-b* of the dielectric sheet **18***a* in the z-axis direction, thus connecting the external terminal **16***a* to the end of the signal line **20** that is located on the negative side in the x-axis direction. The via-hole conductor b2 pierces through the connecting portion **18***a-c* of the dielectric sheet **18***a* in the z-axis direction, thus connecting the external terminal **16***b* to the end of the signal line **20** that is located on the positive side in the x-axis direction. As a result, the signal line **20** is connected between the external terminals **16***a* and **16***b*. The via-hole conductors b1 and b2 are formed preferably by providing a metallic material in through-holes made in the dielectric sheet **18***a*.

The via-hole conductors B1 pierce through the line portion **18***a-a* of the dielectric sheet **18***a* in the z-axis direction. The via-hole conductors B1 are aligned in the x-axis direction so as to be positioned on the positive side in the y-axis direction relative to the bridge portions **59** and **60**, as shown in FIG. **2**. The via-hole conductors B2 pierce through the line portion

18_b-a_ of the dielectric sheet **18**_b_ in the z-axis direction. The via-hole conductors B2 are aligned in the x-axis direction so as to be positioned on the positive side in the y-axis direction relative to the bridge portions **59** and **60**, as shown in FIG. **2**. The via-hole conductors B1 and B2 are paired and connected, such that each pair constitutes a single via-hole conductor, thus connecting the reference ground conductor **22** and the auxiliary ground conductor **24**. The via-hole conductors B1 and B2 are preferably formed by providing a metallic material in through-holes made in the dielectric sheets **18**_a_ and **18**_b_.

The via-hole conductors B3 pierce through the line portion **18**_a-a_ of the dielectric sheet **18**_a_ in the z-axis direction. The via-hole conductors B3 are aligned in the x-axis direction so as to be positioned on the negative side in the y-axis direction relative to the bridge portions **59** and **60**, as shown in FIG. **2**. The via-hole conductors B4 pierce through the line portion **18**_b-a_ of the dielectric sheet **18**_b_ in the z-axis direction. The via-hole conductors B4 are aligned in the x-axis direction so as to be positioned on the negative side in the y-axis direction relative to the bridge portions **59** and **60**, as shown in FIG. **2**. The via-hole conductors B3 and B4 are paired and connected, such that each pair constitutes a single via-hole conductor, thus connecting the reference ground conductor **22** and the auxiliary ground conductor **24**. The via-hole conductors B3 and B4 are preferably formed by providing a metallic material in through-holes made in the dielectric sheets **18**_a_ and **18**_b_.

The protective layer **14** is an insulating film that covers approximately the entire front surface of the dielectric sheet **18**_a_. Accordingly, the protective layer **14** covers the reference ground conductor **22** as well. The protective layer **14** is made of, for example, flexible resin such as a resist material.

Furthermore, the protective layer **14** includes a line portion **14**_a_ and connecting portions **14**_b_ and **14**_c_, as shown in FIG. **2**. The line portion **14**_a_ covers the front surface of the line portion **18**_a-a_ entirely, thus covering the line portion **22**_a_.

The connecting portion **14**_b_ is connected to the end of the line portion **14**_a_ on the negative side in the x-axis direction, and covers the front surface of the connecting portion **18**_a-b_. The connecting portion **14**_b_ includes openings Ha to Hd provided therein. The opening Ha is a rectangular or substantially rectangular opening provided at the center of the connecting portion **14**_b_. The external terminal **16**_a_ is exposed to the outside through the opening Ha. The opening Hb is a rectangular or substantially rectangular opening provided on the positive side in the y-axis direction relative to the opening Ha. The opening Hc is a rectangular or substantially rectangular opening provided on the negative side in the x-axis direction relative to the opening Ha. The opening Hd is a rectangular or substantially rectangular opening provided on the negative side in the y-axis direction relative to the opening Ha. The terminal portion **22**_b_ is exposed to the outside through the openings Hb to Hd, so as to define and function as an external terminal.

The connecting portion **14**_c_ is connected to the end of the line portion **14**_a_ that is located on the positive side in the x-axis direction, and covers the front surface of the connecting portion **18**_a-c_. The connecting portion **14**_c_ includes openings He to Hh provided therein. The opening He is a rectangular or substantially rectangular opening provided at the center of the connecting portion **14**_c_. The external terminal **16**_b_ is exposed to the outside through the opening He. The opening Hf is a rectangular or substantially rectangular opening provided on the positive side in the y-axis direction relative to the opening He. The opening Hg is a rectangular or substantially rectangular opening provided on the positive side in the x-axis direction relative to the opening He. The opening Hh is a rectangular or substantially rectangular opening provided on the negative side in the y-axis direction relative to the opening He. The terminal portion **22**_c_ is exposed to the outside through the openings Hf to Hh, and therefore defines and functions as an external terminal.

In the case of the flat cable **10** thus configured, the characteristic impedance of the signal line **20** cyclically fluctuates between impedance values Z1 and Z2. More specifically, there is relatively low capacitance created between the signal line **20** and the reference ground conductor **22** and also between the signal line **20** and the auxiliary ground conductor **24**, where the signal line **20** overlaps with the openings **29** and **30**. Therefore, the characteristic impedance of the signal line **20** takes the value Z1, which is relatively high, where the signal line **20** overlaps with the openings **29** and **30**.

On the other hand, there is relatively high capacitance created between the signal line **20** and the reference ground conductor **22** and also between the signal line **20** and the auxiliary ground conductor **24**, where the signal line **20** overlaps with the bridge portions **59** and **60**. Therefore, the characteristic impedance of the signal line **20** takes the value Z2, which is relatively low, where the signal line **20** overlaps with the bridge portions **59** and **60**. The openings **29** and the bridge portions **59** alternate with each other in the x-axis direction, and the openings **30** and the bridge portions **60** alternate with each other in the x-axis direction. Accordingly, the characteristic impedance of the signal line **20** cyclically fluctuates between the impedance values Z1 and Z2. The impedance value Z1 is, for example, 55Ω, and the impedance value Z2 is, for example, 45Ω. The average characteristic impedance of the entire signal line **20** is, for example, 50Ω.

The connectors **100**_a_ and **100**_b_ are mounted on the front surfaces of the connecting portions **12**_b_ and **12**_c_, respectively, as shown in FIG. **1**. The connectors **100**_a_ and **100**_b_ have the same configuration, and therefore, the configuration of the connector **100**_b_ will be taken as an example in the following description. FIG. **5**A is an external oblique view of the connector **100**_b_ of the flat cable **10**, and FIG. **5**B is a cross-sectional structure view of the connector **100**_b_.

The connector **100**_b_ includes a connector body **102**, external terminals **104** and **106**, a center conductor **108**, and an external conductor **110**, as shown in FIGS. **1**, **5**A, and **5**B. The connector body **102** includes a rectangular or substantially rectangular plate member and a cylindrical or substantially cylindrical member coupled thereon, and is made of an insulating material such as resin.

The external terminal **104** is positioned on the plate member of the connector body **102** on the negative side in the z-axis direction, so as to face the external terminal **16**_b_. The external terminal **106** is positioned on the plate member of the connector body **102** on the negative side in the z-axis direction, so as to correspond to the portions of the terminal portion **22**_c_ that are exposed from the openings Hf to Hh.

The center conductor **108** is positioned at the center of the cylindrical member of the connector body **102**, and is connected to the external terminal **104**. The center conductor **108** is a signal terminal to/from which a high-frequency signal is inputted/outputted. The external conductor **110** is positioned on the inner circumferential surface of the cylindrical member of the connector body **102**, and is connected to the external terminal **106**. The external conductor **110** is a ground terminal to be kept at a ground potential.

The connector **100**_b_ thus configured is mounted on the front surface of the connecting portion **12**_c_, as shown in FIG. **5**, such that the external terminal **104** is connected to the external terminal **16**_b_, and the external terminal **106** is connected to the terminal portion **22**_c_. As a result, the signal line **20** is electrically connected to the center conductor **108**. In addition, the reference ground conductor **22** and the auxiliary ground conductor **24** are electrically connected to the external conductor **110**.

Note that the connectors **100***a* and **100***b* do not have to be provided. Specifically, external connections may be provided, for example, by disposing the external terminals **104** and **106** on the front surfaces of the connecting portions **12***b* and **12***c* as electrodes for external connections.

The flat cable **10** is used in the manner as will be described below. FIGS. **6**A and **6**B illustrate an electronic device **200** provided with the flat cable **10** as viewed in plan views in the y-axis and z-axis directions, respectively.

The electronic device **200** includes the flat cable **10**, circuit boards **202***a* and **202***b*, receptacles **204***a* and **204***b*, a battery pack (metallic object) **206**, and a housing **210**.

For example, the circuit board **202***a* has provided thereon a transmission or reception circuit including an antenna. The circuit board **202***b* includes, for example, a power circuit provided thereon. The battery pack **206** is, for example, a lithium-ion secondary battery, and the surface thereof is wrapped by a metal cover. The circuit board **202***a*, the battery pack **206**, and the circuit board **202***b* are arranged in this order, from the negative side to the positive side in the x-axis direction.

The receptacles **204***a* and **204***b* are provided on the principal surfaces of the circuit boards **202***a* and **202***b*, respectively, on the negative side in the z-axis direction. The receptacles **204***a* and **204***b* are connected to the connectors **100***a* and **100***b*, respectively. As a result, high-frequency signals to be transmitted between the circuit boards **202***a* and **202***b* at a frequency of, for example, about 2 GHz are applied to the center conductors **108** of the connectors **100***a* and **100***b* via the receptacles **204***a* and **204***b*, respectively. Moreover, the external conductors **110** of the connectors **100***a* and **100***b* are kept at a ground potential by the circuit boards **202***a* and **202***b* and the receptacles **204***a* and **204***b*. Thus, the flat cable **10** connects the circuit boards **202***a* and **202***b*.

Here, the front surface of the dielectric element assembly **12** (more specifically, the protective layer **14**) is in contact with the battery pack **206**. The dielectric element assembly **12** and the battery pack **206** are fixed by an adhesive or the like. The front surface of the dielectric element assembly **12** is a principal surface positioned on the side of the reference ground conductor **22** relative to the signal line **20**. Accordingly, the reference ground conductor **22** provided with the openings **29**, which are relatively small-sized, is positioned between the signal line **20** and the battery pack **206**.

Note that in the case of the flat cable **10** used in the electronic device **200** shown in FIGS. **6**A and **6**B, the connectors **100***a* and **100***b* are connected to the receptacles **204***a* and **204***b*, thus connecting the circuit boards **202***a* and **202***b*, but, for example, the flat cable **10** does not have to be provided with the connectors, and may be provided with electrodes for external connections, which are connected to land electrodes of the circuit boards **202***a* and **202***b* by conductive materials or the like.

The method for producing the flat cable **10** will be described below with reference to FIG. **2**. While the following description focuses on one flat cable **10** as an example, in actuality, large-sized dielectric sheets are laminated and cut, so that a plurality of flat cables **10** are produced at the same time.

Prepared first are dielectric sheets **18***a* to **18***c* made of a thermoplastic resin and having their entire front surfaces copper-foiled (i.e., coated with metal films). More specifically, copper foil is attached to the front surfaces of the dielectric sheets **18***a* to **18***c*. Moreover, the copper-foiled surfaces of the dielectric sheets **18***a* to **18***c* are smoothened, for example, by galvanization for rust prevention. The dielectric sheets **18***a* to **18***c* preferably are sheets of liquid crystal polymer. The thickness of the copper foil preferably is about 10 μm to about 20 μm, for example.

Next, external terminals **16***a* and **16***b* and a reference ground conductor **22**, as shown in FIG. **2**, are formed on the front surface of the dielectric sheet **18***a* preferably by patterning the copper foil on the front surface of the dielectric sheet **18***a*. More specifically, resists are printed on the copper foil on the front surface of the dielectric sheet **18***a* in the same patterns as the external terminals **16***a* and **16***b* and the reference ground conductor **22** shown in FIG. **2**. Then, any portions of the copper foil that are not coated with the resists are removed by etching. Thereafter, the resists are removed by spraying a resist liquid thereon. As a result, the external terminals **16***a* and **16***b* and the reference ground conductor **22** are formed on the front surface of the dielectric sheet **18***a* by photolithography, as shown in FIG. **2**.

Next, a signal line **20**, as shown in FIG. **2**, is formed on the front surface of the dielectric sheet **18***b*. In addition, an auxiliary ground conductor **24**, as shown in FIG. **2**, is formed on the front surface of the dielectric sheet **18***c*. Note that the above steps of forming the signal line **20** and the auxiliary ground conductor **24** are similar to the steps for forming the external terminals **16***a* and **16***b* and the reference ground conductor **22**, and therefore, any descriptions thereof will be omitted.

Next, via-holes are bored through the dielectric sheets **18***a* and **18***b* by irradiating the sheets with laser beams where via-hole conductors b1, b2, and B1 to B4 are to be formed. Thereafter, the via-holes are filled with a conductive paste, thus forming the via-hole conductors b1, b2, and B1 to B4. Note that instead of forming the via-hole conductors b1, b2, and B1 to B4, through-hole conductors may be formed, for example, by plating through-holes for interlayer connection of the dielectric sheet **18***a*.

Next, the dielectric sheets **18***a* to **18***c* are stacked in this order, from the positive side to the negative side in the z-axis direction, thus forming a dielectric element assembly **12**. Thereafter, the dielectric sheets **18***a* to **18***c* are heated and pressed from both the positive and negative sides in the z-axis direction, such that the dielectric sheets **18***a* to **18***c* are integrated.

Next, a resin (resist) paste is applied to the front surface of the dielectric sheet **18***a* by screen printing, thus forming a protective layer **14** on the front surface of the dielectric sheet **18***a* so as to cover the reference ground conductor **22**.

Lastly, connectors **100***a* and **100***b* are soldered to the external terminals **16***a* and **16***b* and terminal portions **22***b* and **22***c* on connecting portions **12***b* and **12***c*. As a result, the flat cable **10** shown in FIG. **1** is obtained.

The flat cable **10** thus configured is significantly reduced in thickness. More specifically, the flat cable **10** includes the openings **29** provided in the reference ground conductor **22** and the openings **30** provided in the auxiliary ground conductor **24**. Accordingly, less capacitance is created between the signal line **20** and the reference ground conductor **22** and also between the signal line **20** and the auxiliary ground conductor **24**. Therefore, even when the distance between the signal line **20** and the reference ground conductor **22** in the z-axis direction and the distance between the signal line **20** and the auxiliary ground conductor **24** in the z-axis direction are reduced, capacitance to be created between the signal line **20** and the reference ground conductor **22** and also between the signal line **20** and the auxiliary ground conductor **24** does not become excessively large. As a result, the characteristic impedance of the signal line **20** can be readily adjusted to a predetermined value (e.g., about 50Ω). Thus, it is possible to reduce the thickness of the flat cable **10** while maintaining the characteristic impedance of the signal line **20** at a predetermined value.

Furthermore, the flat cable **10** renders it possible to prevent fluctuations in the characteristic impedance of the signal line **20**. More specifically, in the flat cable **10**, the openings **29** are smaller than the openings **30**. More specifically, the width W1 of the openings **29** is less than the width W2 of the openings **30**, and the length L1 of the openings **29** is less than the length L2 of the openings **30**. Accordingly, the front surface of the flat cable **10** is attached to the battery pack **206**. The front surface of the flat cable **10** is a principal surface located on the side of the reference ground conductor **22** relative to the signal line **20**. The reference ground conductor **22** has the relatively small-sized openings **29** provided therein. As a result, the flat cable **10** has only a small number of lines of electric force directed from the signal line **20** through the openings **29** toward the battery pack **206**. Therefore, floating capacitance created between the signal line **20** and the battery pack **206** is reduced, so that the characteristic impedance of the signal line **20** is prevented from fluctuating. In addition, since less floating capacitance is created between the signal line **20** and the battery pack **206**, the flat cable **10** and the battery pack **206** are disposed close to each other.

Furthermore, the flat cable **10** renders it possible to achieve reduction in insertion loss. More specifically, in the case of the flat cable **10**, when a current i1 flows through the signal line **20**, a feedback current (countercurrent) i2 flows through the reference ground conductor **22**, and a feedback current (countercurrent) i3 flows through the auxiliary ground conductor **24**, as shown in FIG. **3**. When the flat cable **10** is viewed in a plan view in the z-axis direction, the edges of the openings **29** do not overlap with the edges of the openings **30**. Accordingly, the position where the feedback current (countercurrent) i2 flows is distanced from the position where the feedback current (countercurrent) i3 flows. As a result, magnetic-field coupling caused by flows of the feedback currents (countercurrents) i2 and i3 is weakened, so that the current i1 can flow more readily, resulting in reduced insertion loss in the flat cable **10**. Moreover, the feedback currents (countercurrents) i2 and i3 flow independently of each other, and therefore, resistance to the currents flowing through the reference ground conductor **22** and the auxiliary ground conductor **24** is low, so that the current i1 flows more readily.

Furthermore, for the following reasons also, the flat cable **10** renders it possible to prevent fluctuations in the characteristic impedance of the signal line **20**. More specifically, the high-frequency signal line described in International Publication No. WO2012/073591 has congruent openings provided in two ground conductors, and the openings overlap with each other completely when viewed in a plan view in the direction of lamination. Accordingly, if the dielectric element assembly of the high-frequency signal line is poorly layered upon lamination so that the layers deviate from one other, the openings also deviate from each other. As a result, the size of the area where the ground conductors face each other changes, resulting in a change in the capacitance to be created between the ground conductors, and causing fluctuations in the characteristic impedance of the signal line.

Therefore, in the flat cable **10**, the openings **29** are positioned within the openings **30** when they are viewed in a plan view in the z-axis direction. This prevents the openings **29** from extending beyond the openings **30** even if the dielectric element assembly **12** is poorly layered upon lamination, resulting in a deviation in the positional relationship between the openings **29** and **30**. That is, the size of the area where the reference ground conductor **22** and the auxiliary ground conductor **24** face each other is prevented from being changed, and the capacitance created between the reference ground conductor **22** and the auxiliary ground conductor **24** is also prevented from being changed, so that the characteristic impedance of the signal line **20** can be prevented from fluctuating.

The configuration of a flat cable according to a first modification of a preferred embodiment of the present invention will be described below with reference to the drawings. FIG. **7** is an exploded view of the dielectric element assembly **12** of the flat cable **10***a* according to the first modification. FIG. **8** is an equivalent circuit diagram where the flat cable **10***a* according to the first modification is attached to the battery pack **206**.

The flat cable **10***a* differs from the flat cable **10** in that it includes floating conductors **70**. The floating conductors **70** are provided on the positive side in the z-axis direction relative to the signal line **20**, and are not connected to other conductors. Moreover, the floating conductors **70** overlap with the openings **29** when viewed in a plan view in the z-axis direction. In the present preferred embodiment, the floating conductors **70** are positioned within the openings **29** on the front surface of the dielectric sheet **18***a* where the reference ground conductor **22** is provided. The floating conductors **70** preferably are rectangular or substantially rectangular portions, smaller than the openings **29** and out of contact with the reference ground conductor **22**.

Since the flat cable **10***a* as above has the floating conductors **70** provided in the openings **29**, spurious radiation is prevented from being emitted to the outside through the openings **29**.

Further, the characteristic impedance of the signal line **20** is prevented from fluctuating. More specifically, in the case of the flat cable **10***a* provided with the floating conductors **70**, capacitance C1 is created between the signal line **20** and each floating conductor **70**, and capacitance C2 is created between the floating conductor **70** and the reference ground conductor **22**, as shown in FIG. **8**. The value of the capacitance C1 is high because the signal line **20** is opposed to the floating conductor **70**. On the other hand, the value of the capacitance C2 is very low because the reference ground conductor **22** is not opposed to the floating conductor **70**. Moreover, the capacitances C1 and C2 are connected in a series, and therefore, the combined value of the capacitances C1 and C2 is equal or approximately equal to the value of the capacitance C2. Accordingly, providing the floating conductors **70** results in a very small increase in the capacitance created between the signal line **20** and the reference ground conductor **22**, which is equal or approximately equal to the value of the capacitance C2. Thus, in the case of the flat cable **10***a*, the characteristic impedance of the signal line **20** fluctuates because of the floating conductors **70**, but such fluctuations are small.

The configuration of a flat cable according to a second modification of a preferred embodiment of the present invention will be described below with reference to the drawings. FIG. **9** illustrates a signal line, a reference ground conductor, and an auxiliary ground conductor of the flat cable **10***b* according to the second modification as viewed in a plan view in the direction of lamination.

The flat cable **10***b* differs from the flat cable **10** in terms of the shapes of the signal line **20** and the openings **29** and **30**. More specifically, the openings **29** and **30** are tapered at both ends in the x-axis direction. That is, the width of each of the openings **29** and **30** in the y-axis direction decreases from vicinities of both ends in the x-axis direction toward the ends.

Furthermore, when the flat cable **10***b* is viewed in a plan view in the z-axis direction, the width Wa of the signal line **20** where it overlaps with the openings **29** and **30** is greater than the width Wb of the signal line **20** where it overlaps with the bridge portions **59** and **60**. More specifically, the signal line **20** is tapered so that its width changes as above.

In the flat cable **10***b*, since the openings **29** and **30** are tapered at both ends in the x-axis direction, the width of the gap between the signal line **20** and the openings **29** and **30** gradually decreases toward the ends in the x-axis direction. Accordingly, the number of magnetic flux lines that pass through the gap gradually decreases toward the ends of each of the openings **29** and **30** in the x-axis direction, and the inductance value of the signal line **20** gradually decreases as well. As a result, the characteristic impedance of the signal line **20** fluctuates more gently, so that high-frequency signal reflection in the signal line **20** is prevented.

Furthermore, in the flat cable **10***b*, less capacitance is created where the signal line **20** overlaps with the openings **29** and **30** between the signal line **20** and the reference ground conductor **22** and also between the signal line **20** and the auxiliary ground conductor **24**. Therefore, even if the width Wa of the signal line **20** is increased in order to reduce insertion loss, capacitance does not become excessively large between the signal line **20** and the reference ground conductor **22** and also between the signal line **20** and the auxiliary ground conductor **24**. Thus, it is possible to prevent fluctuations in the characteristic impedance of the signal line **20** and also reduce insertion loss in the flat cable **10***b*.

Other Preferred Embodiments

The present invention is not limited to the flat cables **10**, **10***a*, and **10***b*, and variations can be made within the spirit and scope of the present invention.

The protective layer **14** has been described as being formed preferably by screen printing, but it may be formed by photolithography, for example.

Furthermore, the length L1 of the opening **29** may be greater than or equal to the length L2 of the opening **30**.

Furthermore, the opening **29**, when viewed in a plan view in the z-axis direction, may extend at least partially beyond the opening **30**.

Furthermore, a metallic object may be used in place of the battery pack **206**. Examples of the metallic object include a housing and a printed circuit board.

While preferred embodiments of the present invention have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art without departing from the scope and spirit of the present invention. The scope of the present invention, therefore, is to be determined solely by the following claims.

What is claimed is:

1. A flat cable comprising:

a dielectric element assembly including a plurality of dielectric layers laminated on each other in a lamination direction;

a linear signal line provided in the dielectric element assembly;

a first ground conductor provided on one side in the direction of lamination relative to the signal line and including a plurality of first openings arranged along the signal line; and

a second ground conductor provided on the other side in the direction of lamination relative to the signal line and including a plurality of second openings arranged along the signal line; wherein

the first ground conductor is more distant from the signal line in the direction of lamination than is the second ground conductor; and

the first openings are smaller than the second openings.

2. The flat cable according to claim **1**, wherein the first openings are narrower than the second openings in a direction perpendicular or substantially perpendicular to a direction in which the signal line extends.

3. The flat cable according to claim **1**, wherein edges of the first openings do not overlap with edges of the second openings when viewed in a plan view in the direction of lamination.

4. The flat cable according to claim **1**, wherein the first openings are positioned within the second openings when viewed in a plan view in the direction of lamination.

5. The flat cable according to claim **1**, wherein

the first ground conductor includes first bridge portions positioned between adjacent first openings;

the second ground conductor includes second bridge portions positioned between adjacent second openings; and

the signal line, when viewed in a plan view in the direction of lamination, is wider in portions that overlap with the first and second openings than in portions that overlap with the first and second bridges.

6. The flat cable according to claim **1**, wherein the dielectric element assembly is flexible.

7. The flat cable according to claim **1**, wherein the dielectric element assembly includes a line portion and connecting portions connected to opposite ends of the line portion, each of the connecting portions having a width greater than a width of the line portion.

8. The flat cable according to claim **1**, wherein the dielectric element assembly includes a line portion and connecting portions connected to opposite ends of the line portion, each of the connecting portions being defined by a rectangular or substantially rectangular portion.

9. The flat cable according to claim **1**, wherein some of the dielectric layers have different thicknesses.

10. The flat cable according to claim **1**, wherein each of the plurality of first opening and the plurality of second openings are rectangular or substantially rectangular.

11. The flat cable according to claim **1**, wherein at least one of the first ground conductor and the second ground conductor has a ladder configuration.

12. The flat cable according to claim **1**, wherein a width of each of the first openings is about 500 μm to about 900 μm and a width of each of the second openings is about 1000 μm to about 2000 μm.

13. The flat cable according to claim **1**, wherein the first openings and the second openings are tapered at both ends thereof.

14. The flat cable according to claim **1**, wherein the linear signal line is tapered.

15. The flat cable according to claim **1**, wherein a length of each of the first openings is equal to or greater than a length of each of the second openings.

16. The flat cable according to claim **1**, wherein the first openings are shorter than the second openings in a direction in which the signal line extends.

17. The flat cable according to claim **16**, wherein a length of each of the first openings is about 2 mm to about 7 mm and a length of the second openings is about 2 mm to about 7 mm.

18. The flat cable according to claim **1**, further comprising floating conductors provided on one side in the direction of lamination relative to the signal line and not connected to other conductors, wherein the floating conductors, when viewed in a plan view in the direction of lamination, overlap with the first openings.

19. The flat cable according to claim **18**, wherein each of the floating conductors is rectangular or substantially rectangular.

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